



An Ocean-Altimetry Measurement Using Reflected GPS Signals Observed from a Low-Altitude Aircraft

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Outline

- Motivation
- Experimental setup
- Delay/Doppler Software receiver
- Signal structure
- Altimetry extraction
- Future work & conclusions

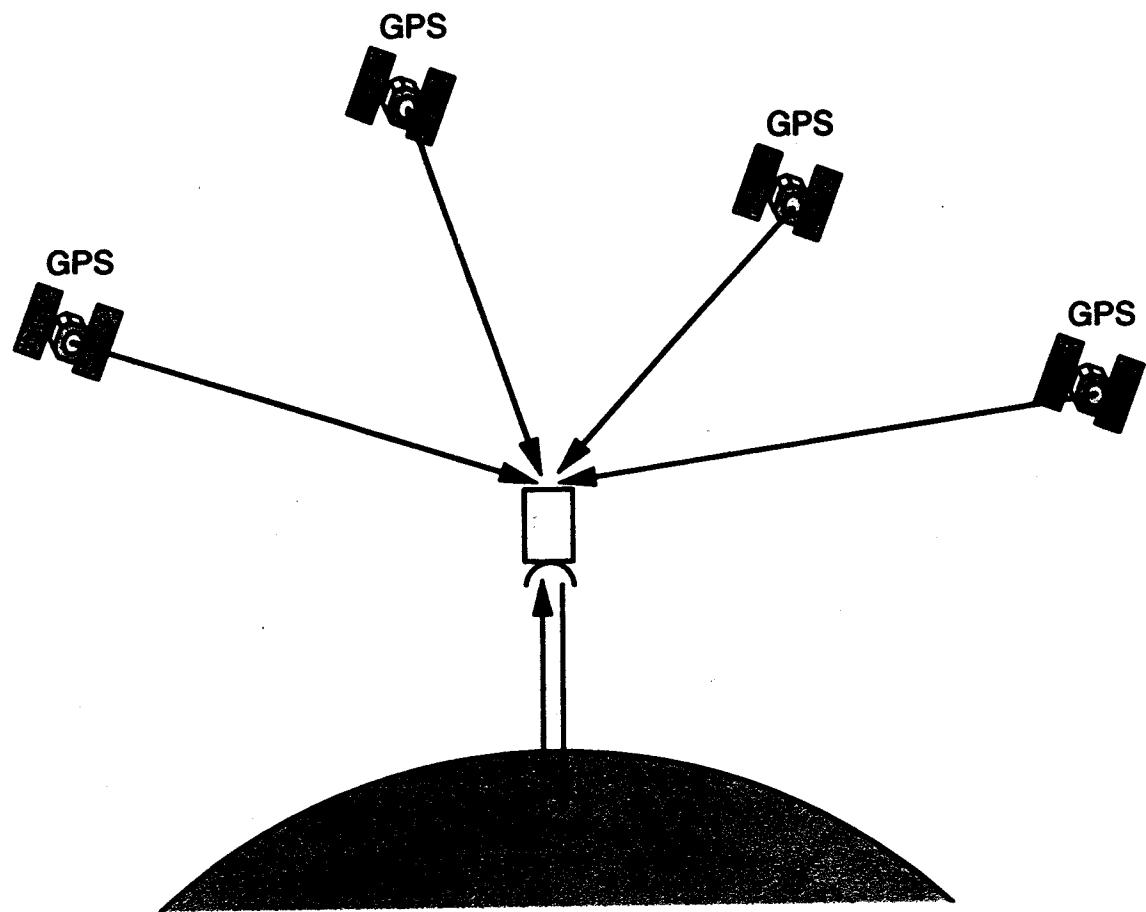


Motivation:

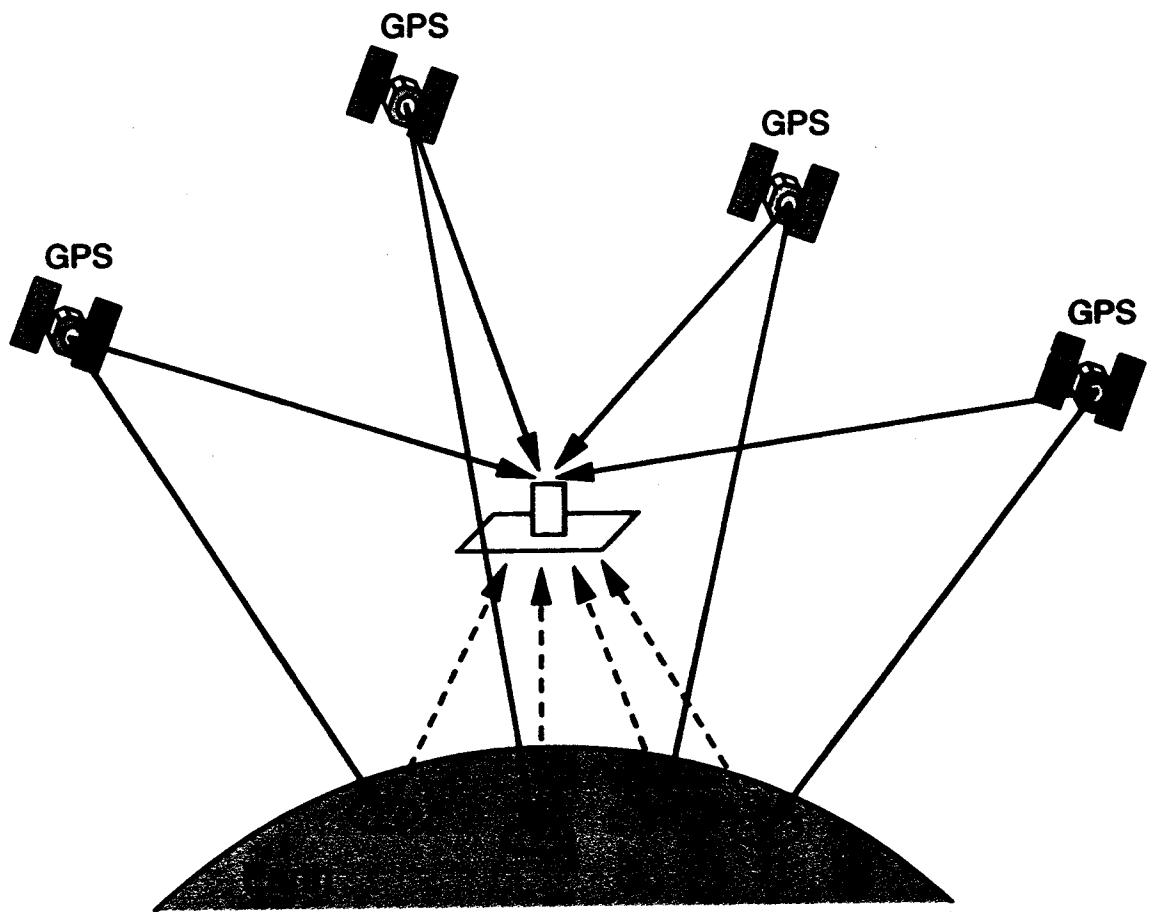
Develop Novel Spaceborne Multi-Static Altimeter

- High spatial/temporal resolution
 - Ocean topography => eddies
 - Improved climate models
- Many similar bistatic GPS applications
 - Ocean wind speed/direction measurements
 - Ice, ice/ocean studies
 - Large-scale land deformation

Mono-Static Altimetry



Multi-Static Altimetry



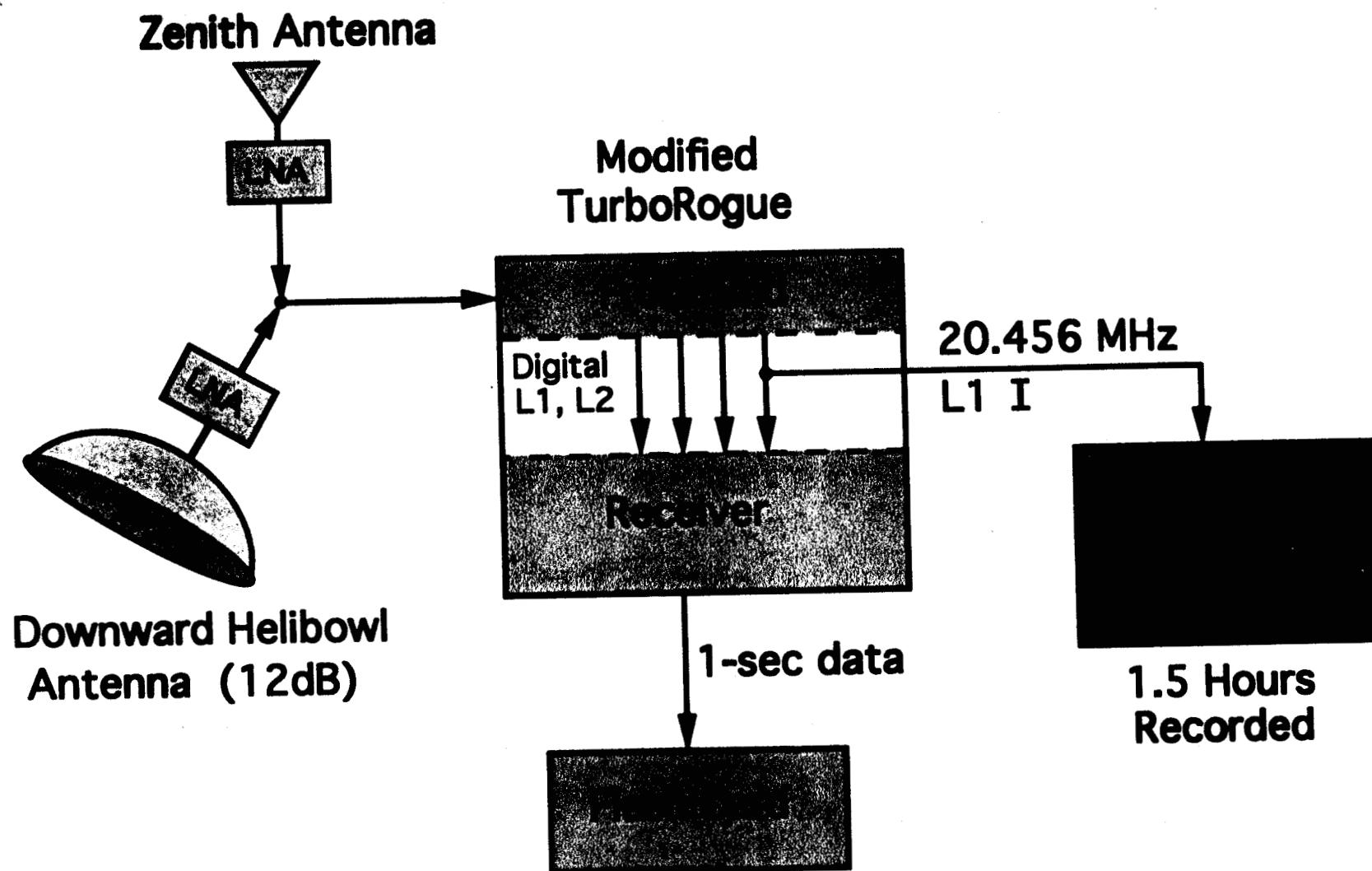


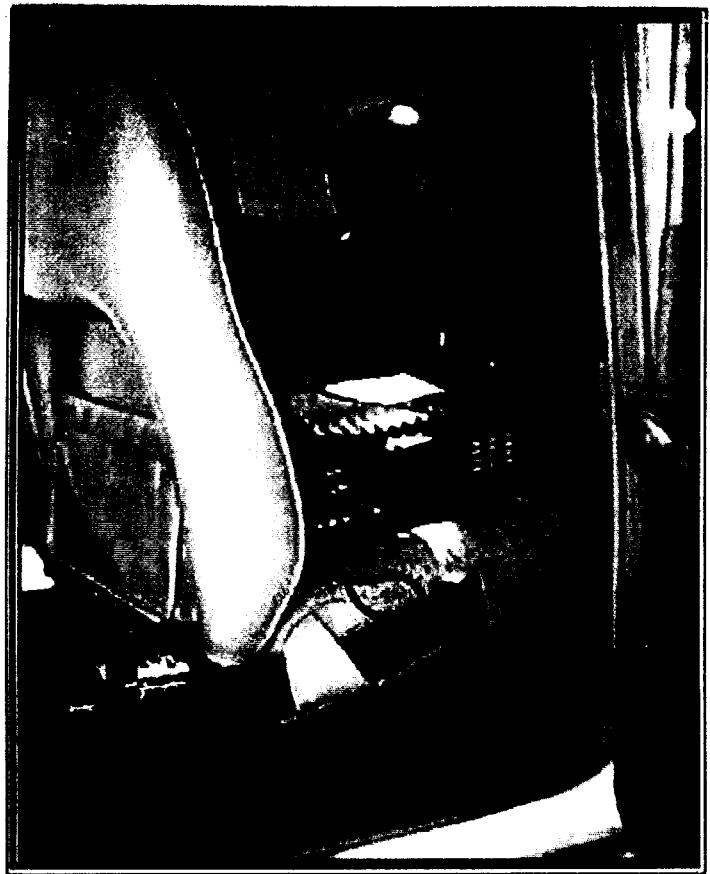
Cessna Experiments: First Step to Space

Testbed for higher flights / LEO opportunities

- Moving platform
- High SNR
- System/algorithm development and error analysis
 - Develop data acquisition system
 - Develop software receiver
 - Develop altimetry extraction algorithms
 - Error budget and link analysis
- Low cost
 - Equipment costs ~\$500

Cessna Experiment







Cessna Flights

- First Flight: Recover Reflected Waveforms
 - Flew over variety of terrain
 - Ocean
 - Lakes (4)
 - Dry Desert
 - Irrigated desert
 - Rough Mountains
 - Urban areas
 - Observed reflections from all terrain types
- Next flights: controlled experiments
 - Focused on altimetry
 - Ground truth

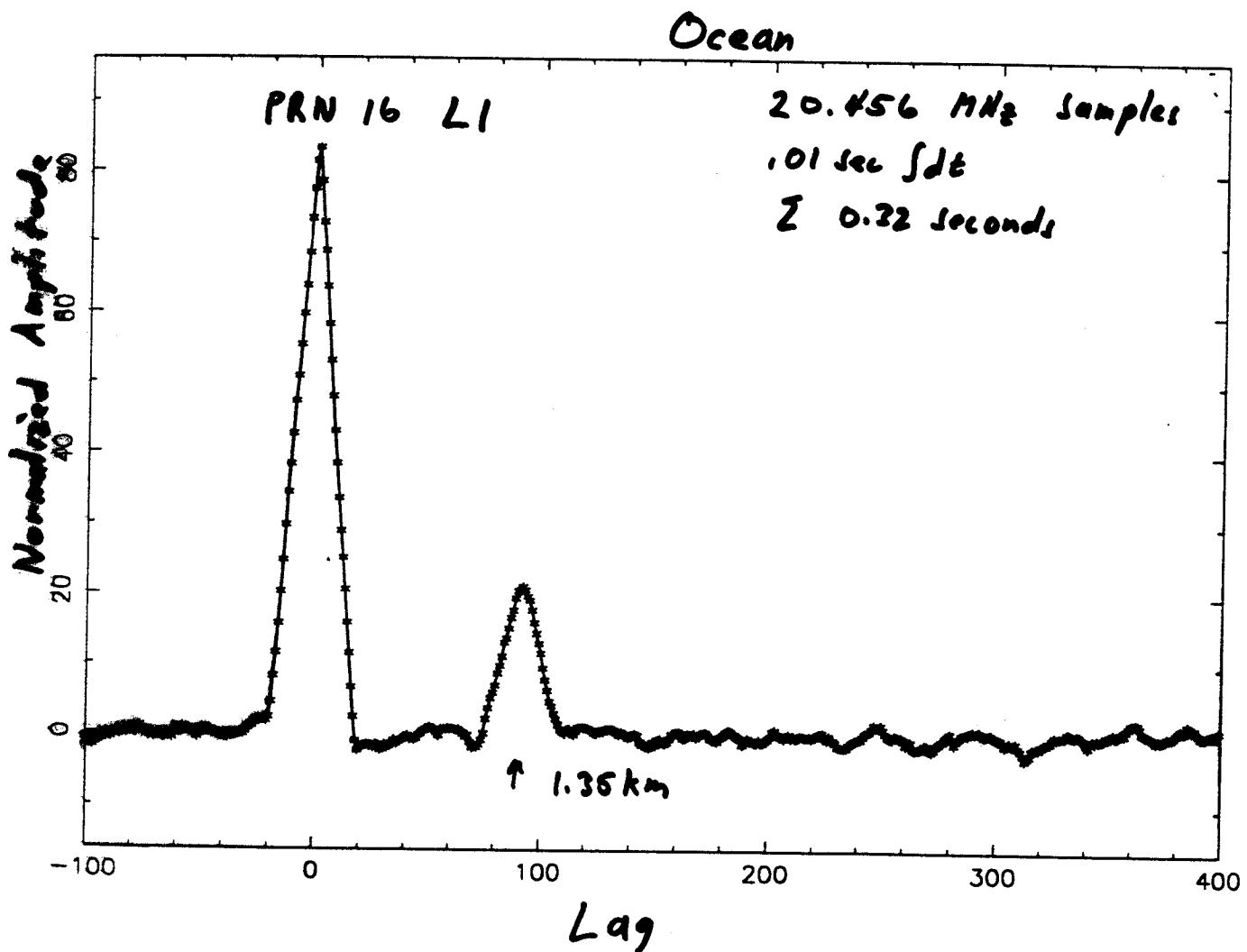


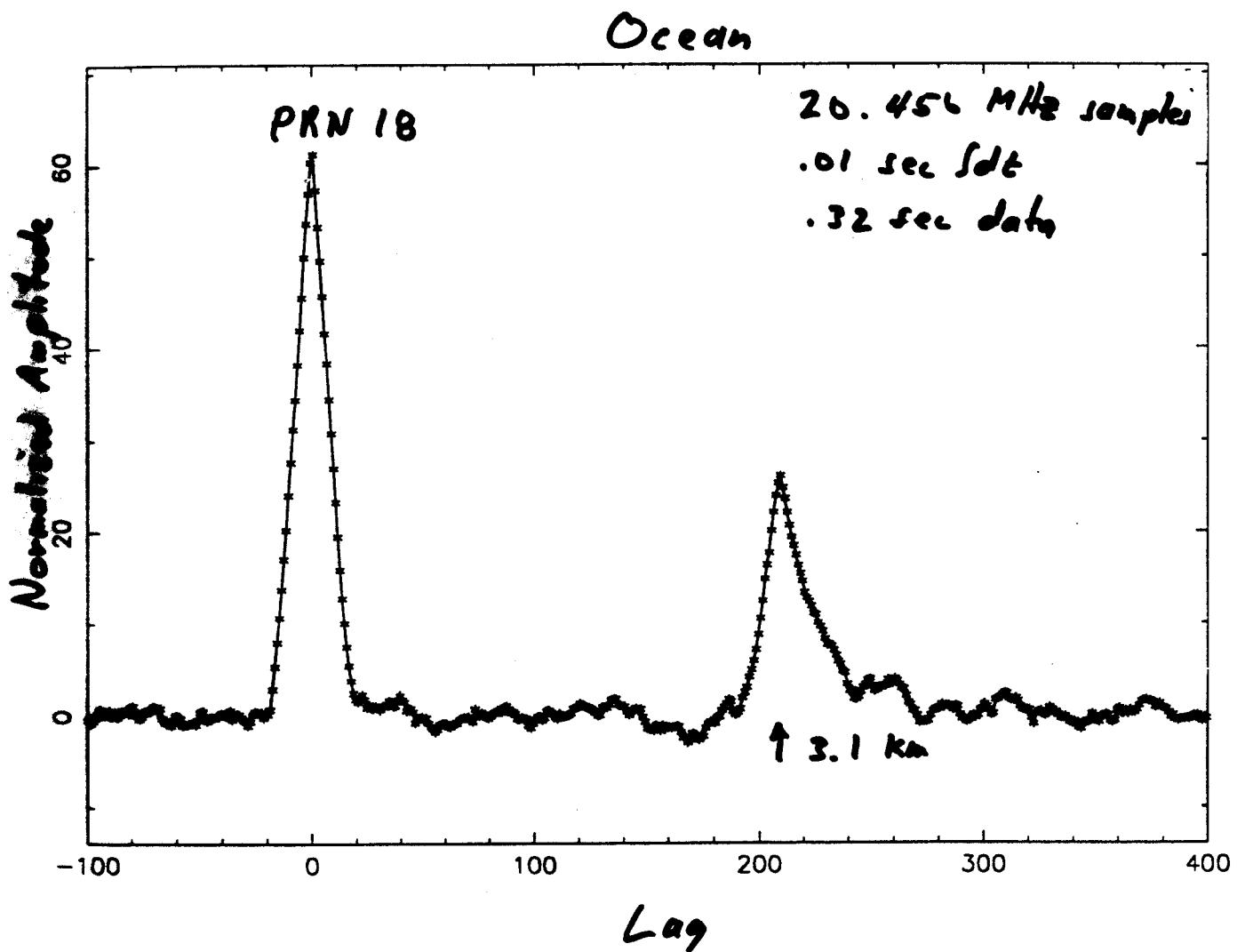
"Software Receiver"

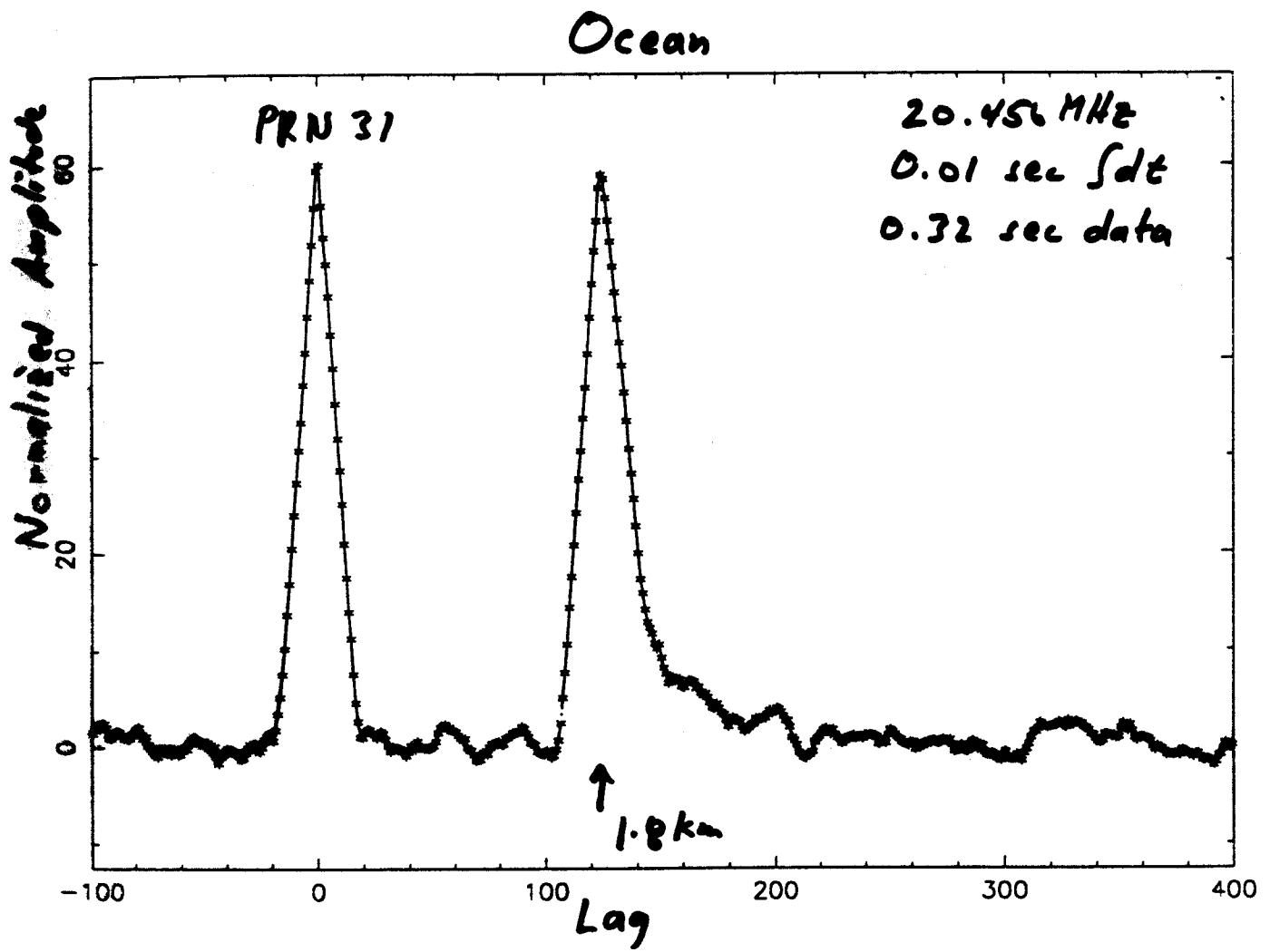
- Ultimate in flexibility
 - Can perform any receiver function
- Current capabilities
 - Phase/Delay tracking
 - Delay/Doppler mapping
 - Unclassified Y-code receiver
 - Navigation message decoding -> timing info
 - Adjustable integration time
 - Usually 0.01 or 0.02 seconds
- Future capabilities
 - Codeless tracking
 - Chilli-con-carne

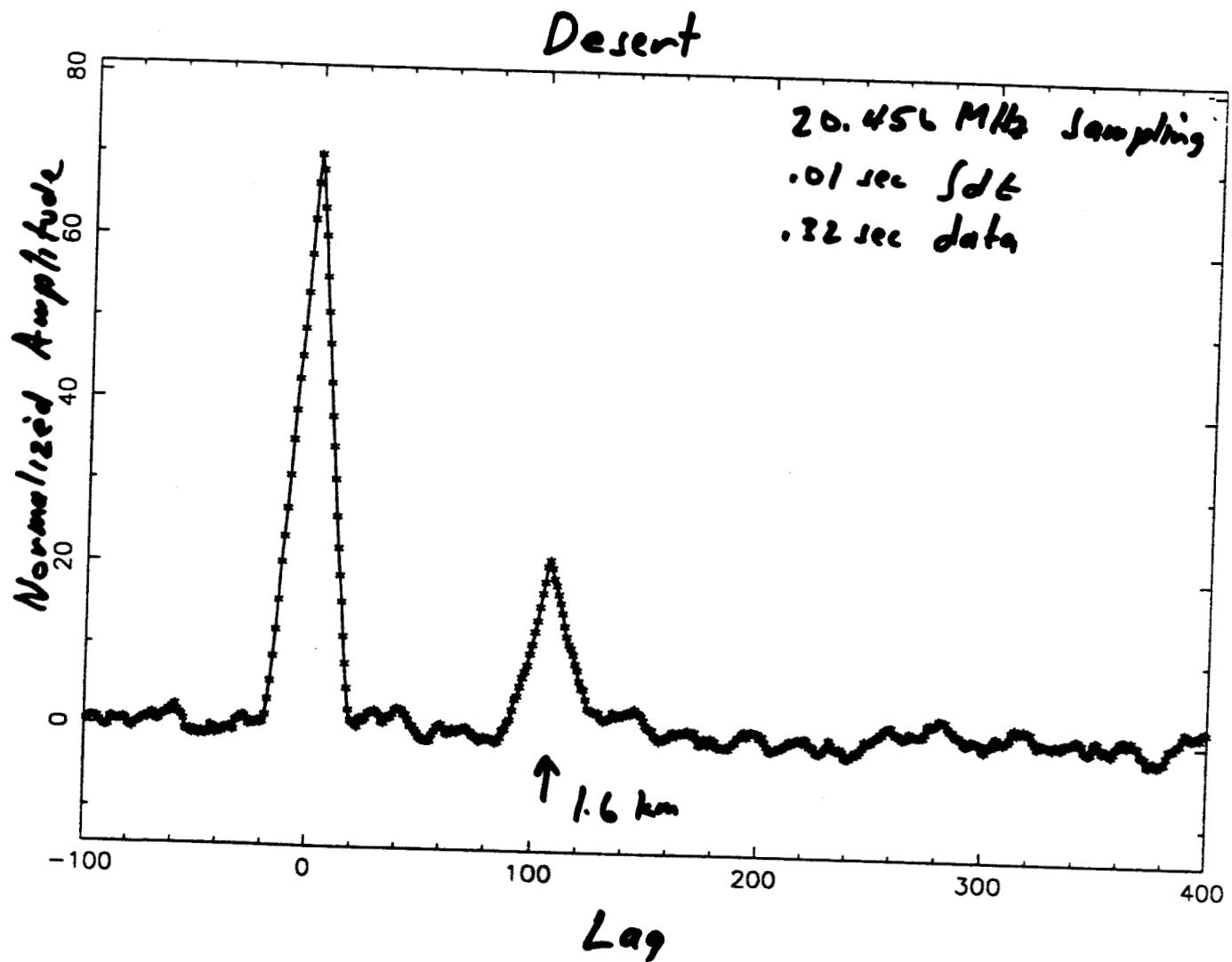
Waveform Extraction

- Cross-Correlate phasor model with data
 - Repeat for large number of lags (FFTs)
 - 10 or 20 msec coherent integrations
 - $\vec{\rho}(\text{lag})$
- Sum amplitudes
 - $A(\text{lag}) = \sum |\vec{\rho}_i(\text{lag})|$
 - 1 sec incoherent summations











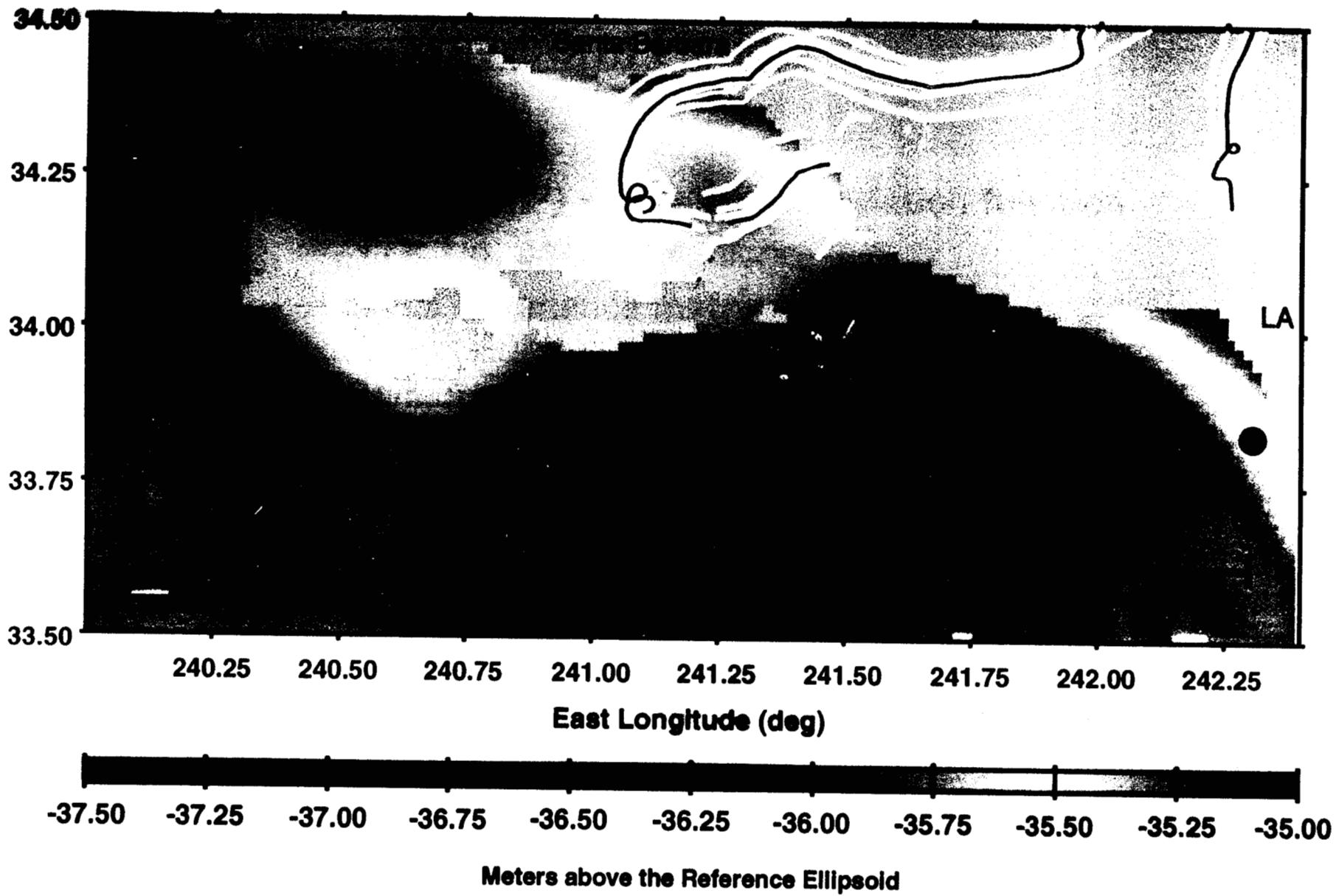
Altimetry Measurement

- Work in Progress
- Select ocean data
 - Only 1-sec position data
- Fit waveforms to determine $\Delta\tau$
- Use all data/PRNs with 1-sec SNR > 50
 - Fit $\Delta\tau(\text{data}) - \Delta\tau(\text{model})$
 - Two parameters: clock error, height error
 - Plot residual delay
- During straight flight path
 - 1-sec points have 5 m RMS
 - => 45 min to obtain 10 cm accuracy

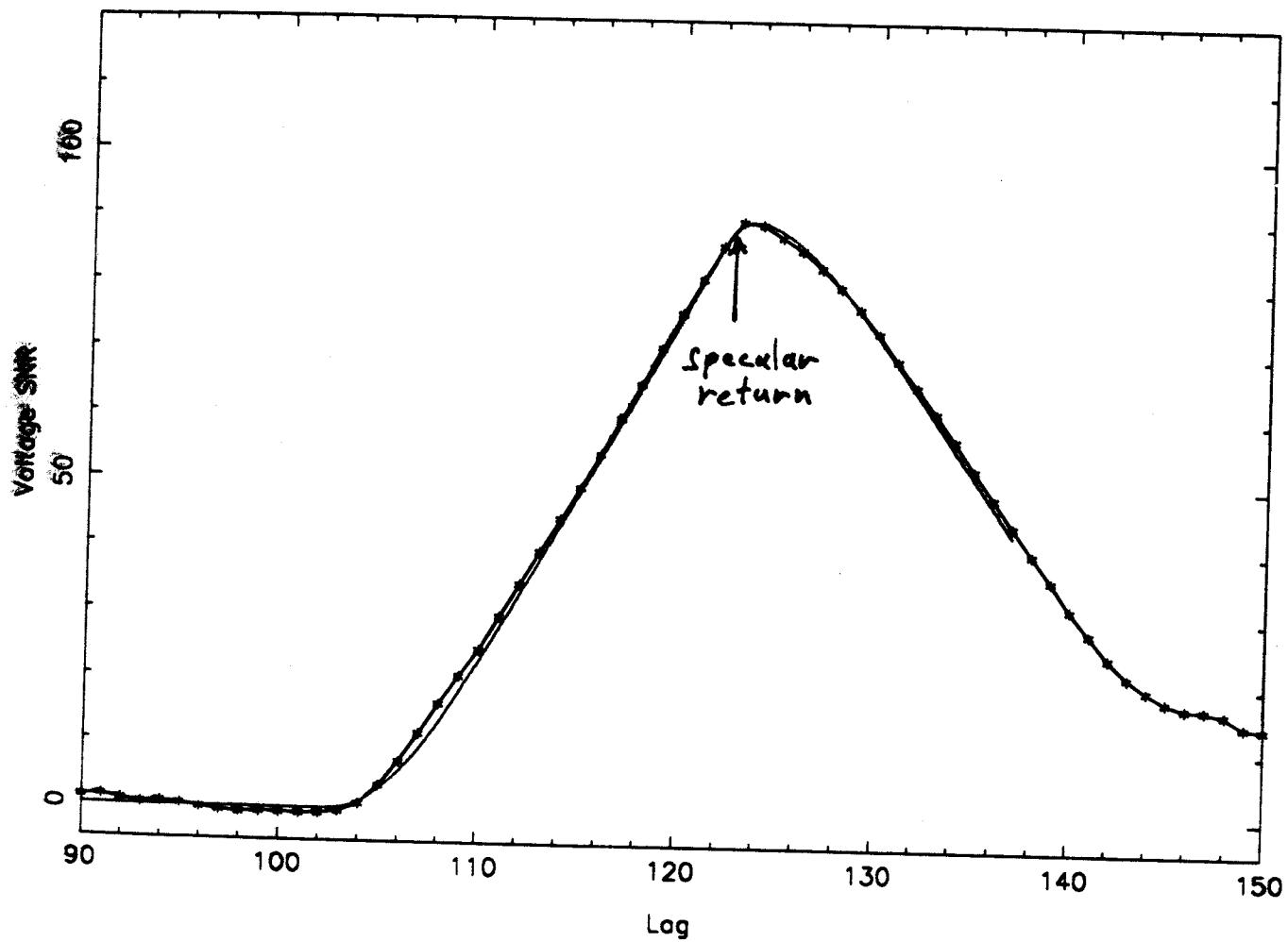
Waveform Fitting

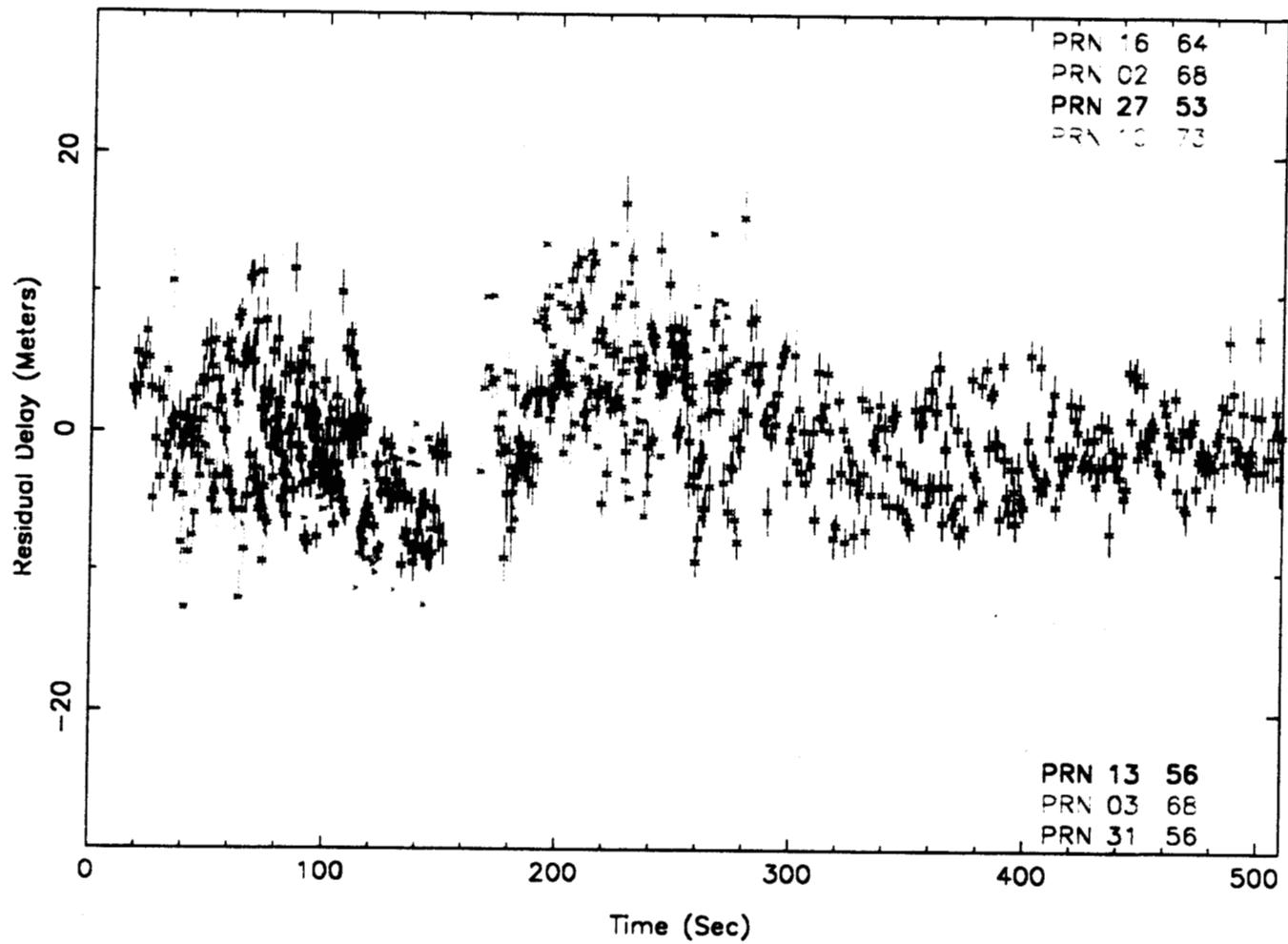
- Direct signal
 - C/A (or P) - code autocorrelation function
 - Fit lag, amplitude, slope
 - Full covariance matrix
- Reflected signal
 - Single model waveform
 - Spirit of Zavorotny-Voronovich
 - Nominal geometry
 - Fit lag, amplitude
 - Full covariance matrix

**Absolute Sea Surface Height off Southern California
(24 Oct 1998 0:25 UTC)**



Example Fit







Potential Systematic Errors

- Fitting with fixed waveform shape
 - Waveform depends on geometry
 - Reflection angles
 - Antenna pointing direction
- C/A code autocorrelation function
 - Sidelobe structure interferes with signal
 - Check Y-code systematics
- 20 msec coherent integration too long
 - 5 or 10 may improve waveforms
- Cessna orientation not recorded
 - Antenna separation vector changes



Future Work

- Continue Assessing Processing Algorithms
 - Test Reflection Models
 - Improve data fitting
 - Understand systematics and their impact
 - Improve Modeling
 - Actual ocean features
 - Tropospheric/ionospheric modeling
 - Cessna orientation (antenna locations)
 - C/A vs. P-code accuracy
- Controlled altimetry experiments
- Develop error budget